The Shapeshifting Universe
Anisotropic Cosmologies from Gravitational Tunneling and their Observational Signatures

based on work with D. Campo and J.C. Niemeyer,
arXiv-eprint:1003.3204

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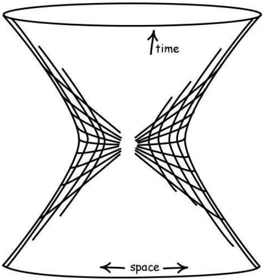
Outline

- Anisotropic Cosmologies from Gravitational Tunneling
  - Compact Extra Dimensions, Flux Compactification
  - “Shapeshifting” Process, Geometry of the Bubble Universe
- Signatures in the CMB
  - Distortion of the CMB Temperature Map
  - The WMAP Measurement
  - Constraint on Anisotropic Curvature

Anisotropic Cosmologies from Grav. Tunneling

A “Landscape” of Compactification Vacua

In theories with extra dimensions there exists a multitude of vacuum solutions of the type



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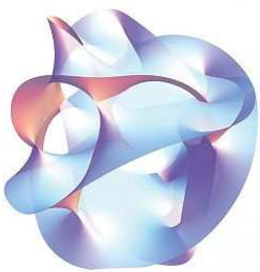


“macroscopic spacetime”

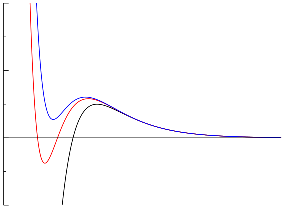
“microscopic compact manifold”

Flux Compactification

Simple example: Einstein-Maxwell theory in higher dimensions

$$\mathcal{S} = \frac{1}{16\pi} \int d^D x \sqrt{-g} \left[\mathcal{R} - 2\Lambda - F^2\right]$$

F: q-form flux $\rightarrow$ compactification of q dimensions on a q-sphere.



Anisotropic Cosmologies from Grav. Tunneling

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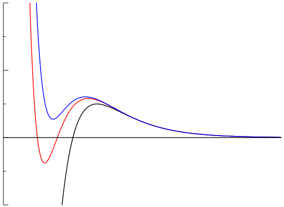

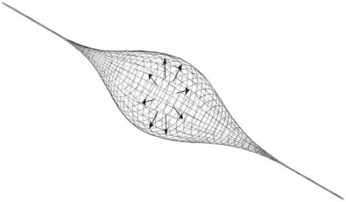

Elementary process: spontaneous (de)compactification.

(Giddings & Myers 2004, Blanco-Pillado, Schwartz-Perlov & Vilenkin 2009, Carroll, Johnson & Randall 2009)

Anisotropic Cosmologies from Grav. Tunneling

Transitions between Compactification Vacua

Shapeshifting process:

$$\begin{pmatrix}\text{pre-transition}\\ \text{macroscopic}\\ \text{universe}\end{pmatrix}_D \times \begin{pmatrix}\text{microscopic}\\ \text{compact}\\ \text{manifold}\end{pmatrix}_d \longrightarrow \begin{pmatrix}\text{bubble}\\ \text{macroscopic}\\ \text{universe}\end{pmatrix}_{D'} \times \begin{pmatrix}\text{microscopic}\\ \text{compact}\\ \text{manifold}\end{pmatrix}_{D+d-D'}$$

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Anisotropic Cosmologies from Grav. Tunneling

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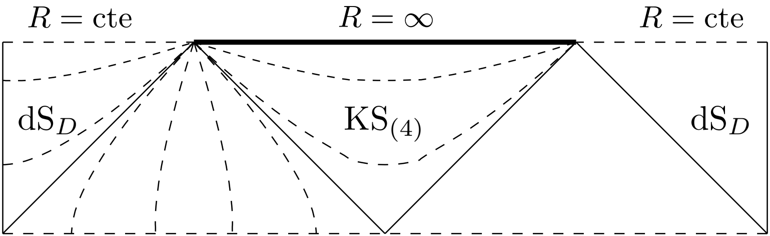
Examples:

compact manifold	cosmological model	curved directions
S_1 (Circle)	Bianchi III	$2 \times$ open $1 \times$ flat
$S_1 \times S_1$ (Torus)	Bianchi I	$3 \times$ flat
S_2 (Sphere)	Kantowski-Sachs	$2 \times$ closed $1 \times$ flat

Spacetime Diagram of a Bubble Universe

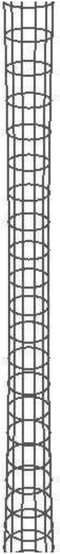
Shapeshifting process (example):

$$\mathsf{dS}_D \times \mathsf{S}_2 \longrightarrow \mathsf{KS}_{(4)} \times \mathcal{M}_{D-2}$$



Anisotropic Cosmologies from Grav. Tunneling

A Shapeshifting Process (Illustration)



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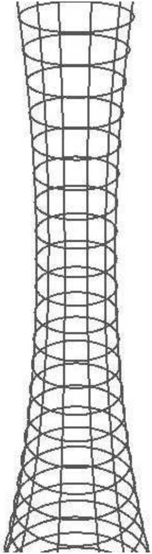

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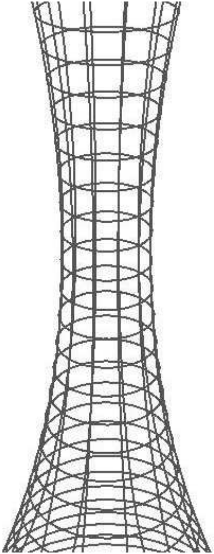

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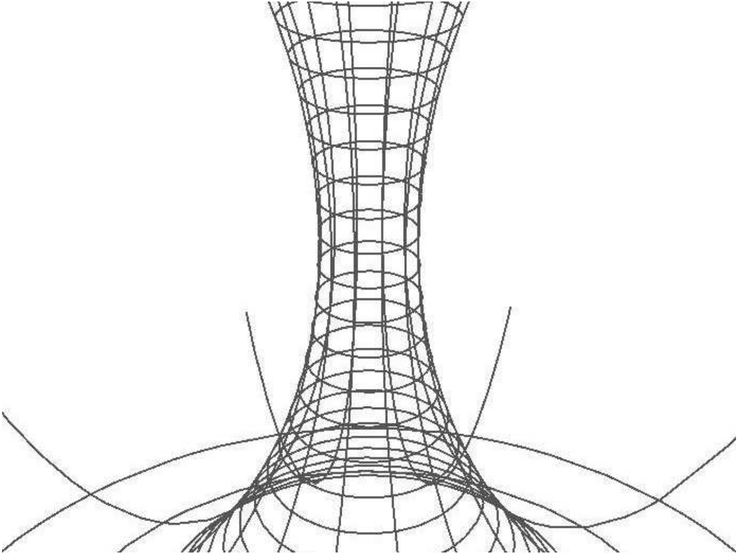

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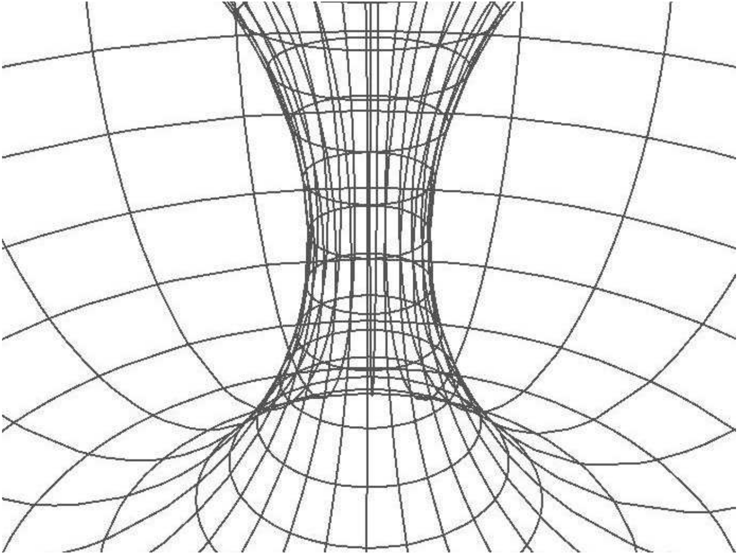

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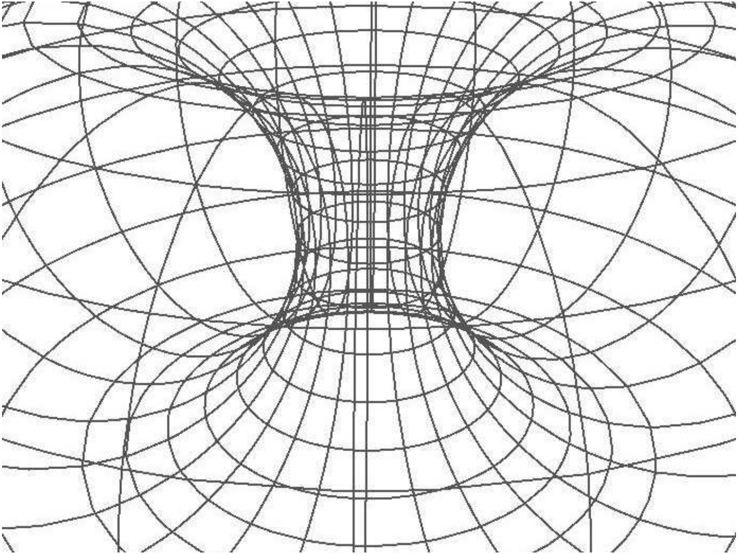

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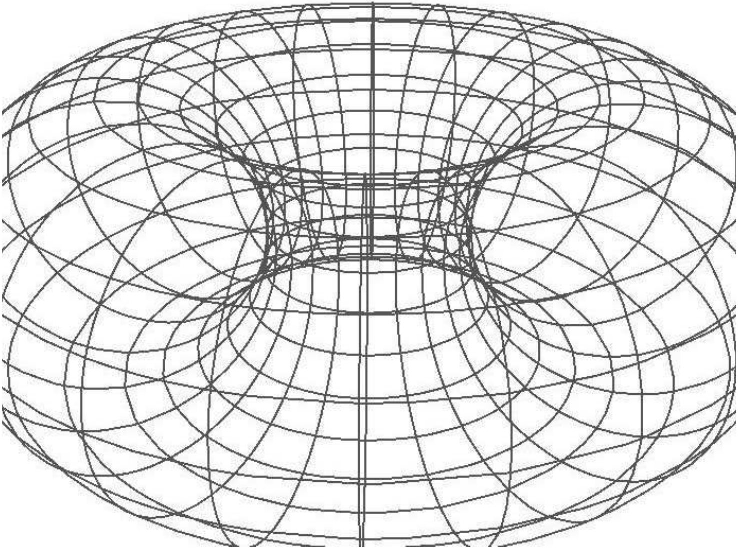

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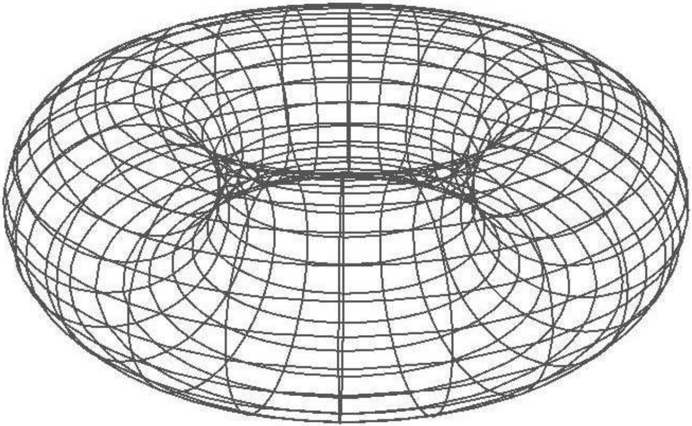

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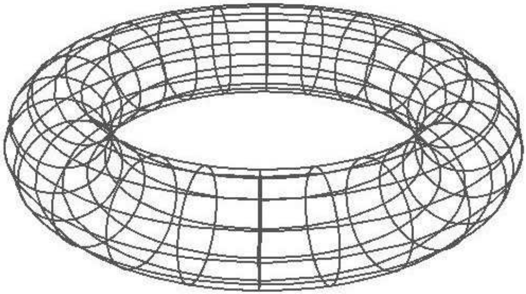

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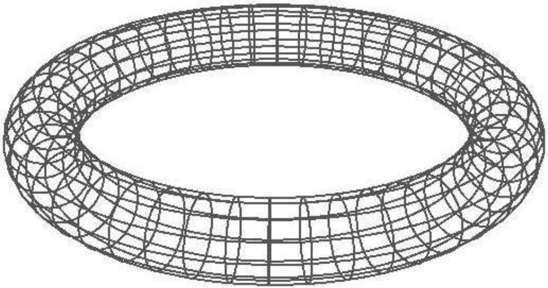

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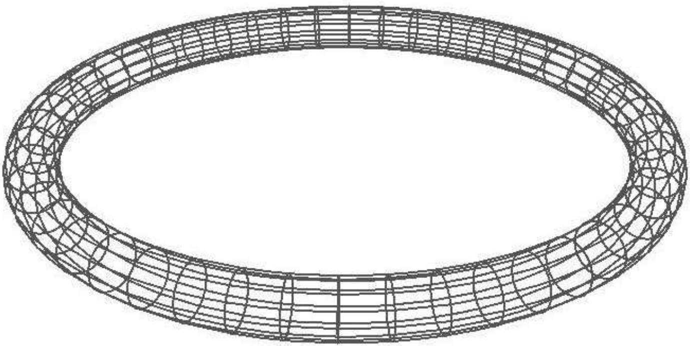

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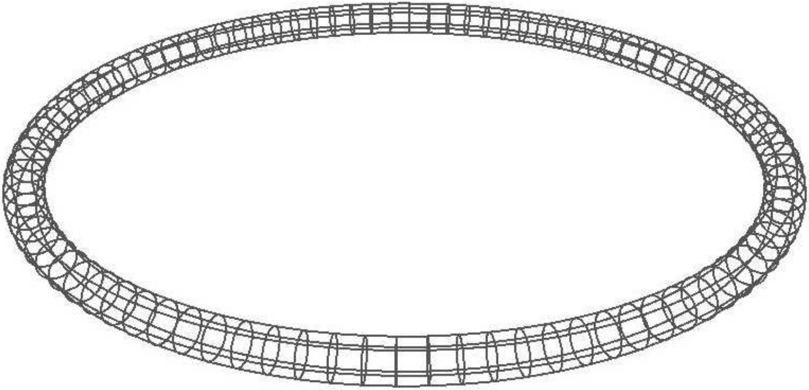

Signatures in the CMB

Anisotropic Curvature

$$\Omega_{\mathsf{curv}} \sim \frac{K}{H^2}$$

cosmological model	curved directions	Ω_{curv}
Bianchi III	$2 \times$ open $1 \times$ flat	< 0
Bianchi I	$3 \times$ flat	$= 0$
Kantowski-Sachs	$2 \times$ closed $1 \times$ flat	> 0

Signatures in the CMB

Distortion of the CMB Temperature Map

Corrections come in at two places:

- Primordial power spectrum
  Kantowski-Sachs (JA, Campo & Niemeyer 2010)
  Bianchi III (Blanco-Pillado & Salem 2010)
- Late universe (photon propagation)
  Sachs-Wolfe effect (Graham, Harnik & Rajendran 2010)

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All modifications are found to have a generic form:

$$T(\theta,\phi) = \left[1 + c\,\Omega_{\mathsf{curv}} Y_{20}(\theta,\phi) + d\,\Omega_{\mathsf{curv}} \partial_\theta Y_{20}(\theta,\phi)\partial_\theta\right] T_0(\theta,\phi)$$

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Stated in terms of a_{lm}'s one finds:

- at fixed l, a non-uniform redistribution of power among m
- correlations between a_{lm} and $a_{l'm}$ for $l' = l \pm 2$

Signatures in the CMB

The Bipolar Coefficients

It is useful to represent the two-point correlation function $\mathcal{C}(\mathbf{n}, \mathbf{n}')$ in the basis of the total angular momentum with eigenvalues L and M:

$$\left\langle \mathbf{n}, \mathbf{n}' | \mathcal{C} \right\rangle = \sum_{l,l',L,M} N^{L}_{ll'} A^{LM}_{ll'} \left\langle \mathbf{n}, \mathbf{n}' | ll'; LM \right\rangle$$

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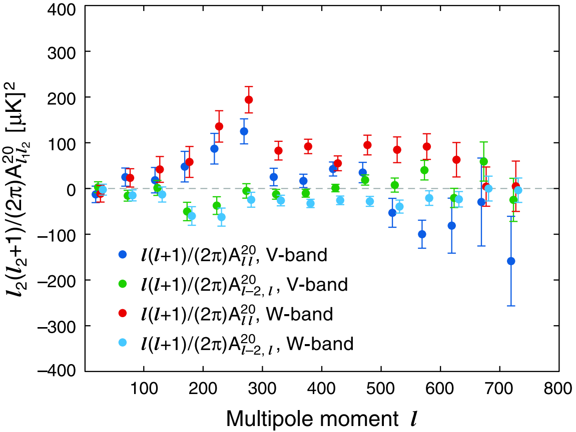
If the field T_0 was statistically isotropic with scale invariant angular power spectrum C_l, we find

$$\begin{aligned} A^{00}_{ll} &= C_l + \mathcal{O}(\Omega^2_{\text{curv}}) \\ A^{20}_{ll} &= C_l \frac{c + 3d}{\sqrt{\pi}} \Omega_{\text{curv}} + \mathcal{O}(\Omega^2_{\text{curv}}) \\ A^{20}_{l-2,l} &= C_l \frac{c\left(l^2 - l + 1\right) - d\left(l^2 - l - 2\right)}{\sqrt{\pi}\left(l^2 - 3l + 2\right)} \Omega_{\text{curv}} + \mathcal{O}(\Omega^2_{\text{curv}}) \end{aligned}$$

Signatures in the CMB

WMAP Measurement



WMAP 7yr data (Bennett *et al.* 2010)
arXiv:1001.4758 [astro-ph.CO]

Signatures in the CMB

The CMB Quadrupole Constraint

$$T(\theta, \phi) = \left[1 + c\,\Omega_{\mathsf{curv}} Y_{20}(\theta, \phi) + d\,\Omega_{\mathsf{curv}} \partial_\theta Y_{20}(\theta, \phi) \partial_\theta\right] T_0(\theta, \phi)$$

- The term $\propto c$ induces a contribution to the quadrupole from the CMB monopole

Signatures in the CMB

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- The term $\propto c$ induces a contribution to the quadrupole from the CMB monopole
- The observed quadrupole of only $\sim 14\mu K$ therefore constrains $|c\,\Omega_{\text{curv}}| \lesssim 10^{-4}$, even taking into account “cosmic variance”
- The term $\propto d$ is much less constrained, $|d\,\Omega_{\text{curv}}| \lesssim 10^{-2}$

Fin

Summary

- **Shapeshifting** (= tunneling between compactification vacua) generically leads to homogeneous but *anisotropic* bubble universes.
- **Anisotropic curvature** produces distinct signatures in the CMB.
- **CMB quadrupole** puts strong constraints on the simplest of such models.

For further reference, see also arXiv-eprint:1003.3204